LLNL-CONF-675653

LAWRENCE LIVERMORE NATIONAL LABORATORY

Neutron Capture Experiments - Filling Nuclear Data Needs for Safeguards

B. W. Sleaford

August 3, 2015

INTERNATIONAL NUCLEAR MATERIALS MANAGEMENT
Indian Wells, CA, United States
July 12, 2015 through July 16, 2015

Neutron Capture Experiments – Filling Nuclear Data Needs for Safeguards

Non Destructive Assay Working Group Meeting

International Nuclear Materials Management

Brad Sleaford

July 12, 2015

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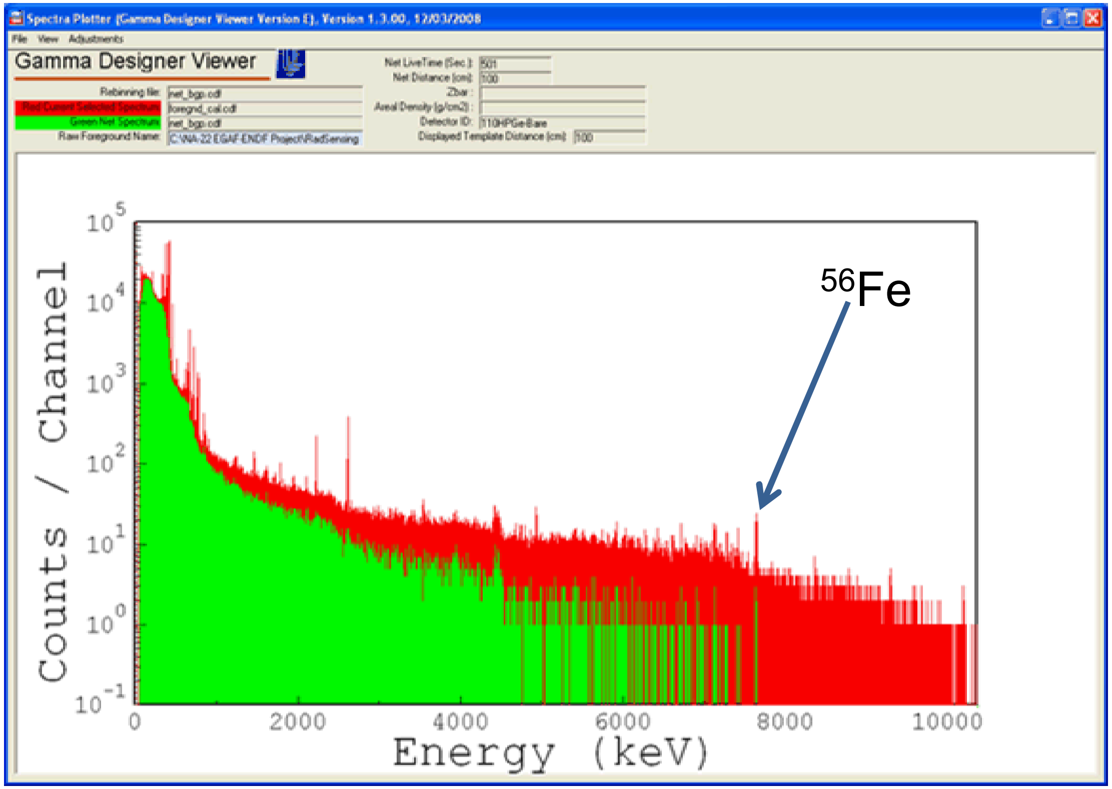
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

-Nuclear Data upgrades for Transport Modeling
-Neutron Capture gamma spectroscopy,
-HPGe detectors

Measurement of gamma spectra from Pu mass-> Want to Model This



Capture Gammas:

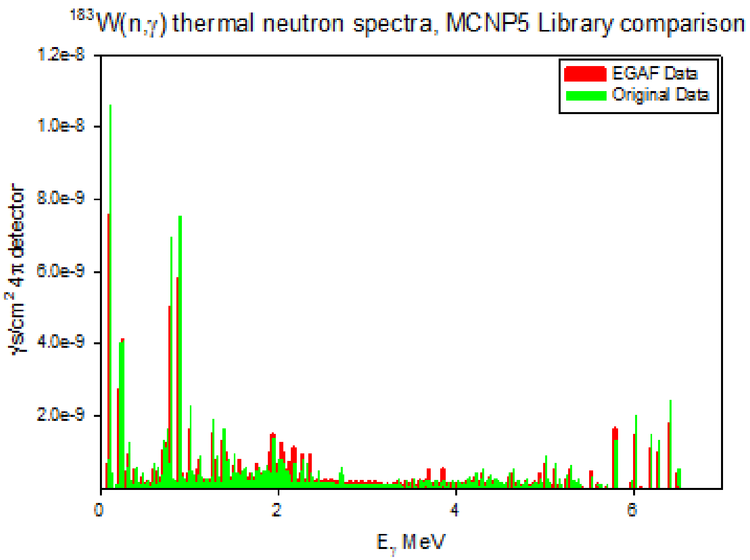
-High Energies to 12 MeV

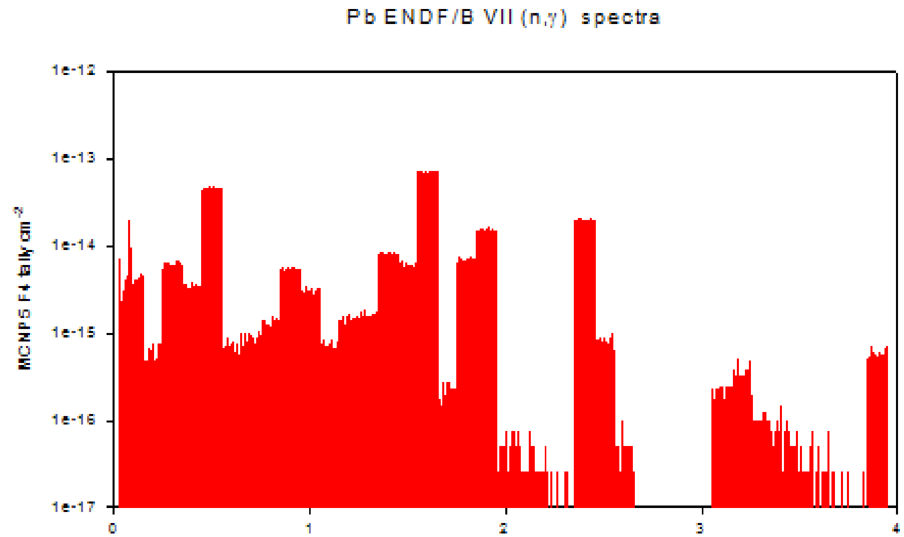
-Fingerprint of Isotope

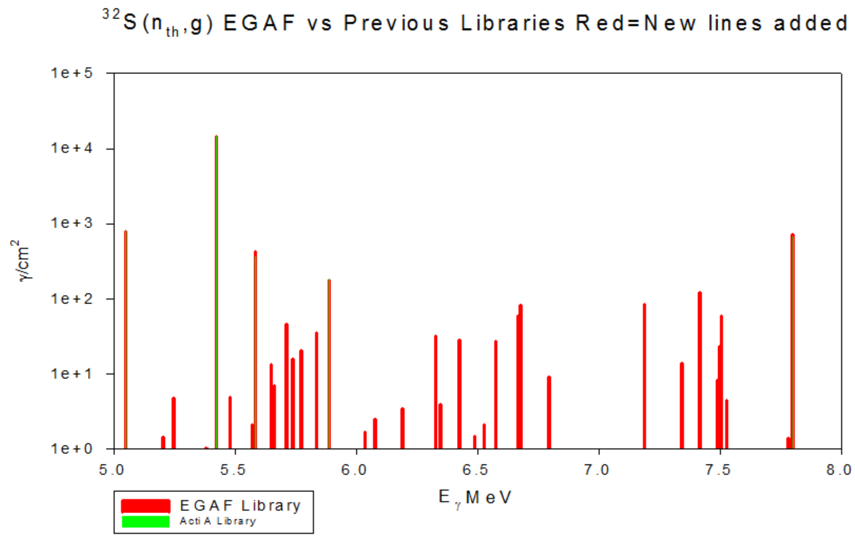
-Neutrons=Actinides

Used in ANY spectroscopy application, Emergency response, Safeguards, etc.

Examples of Missing Capture Data and some improvements for Transport Applications



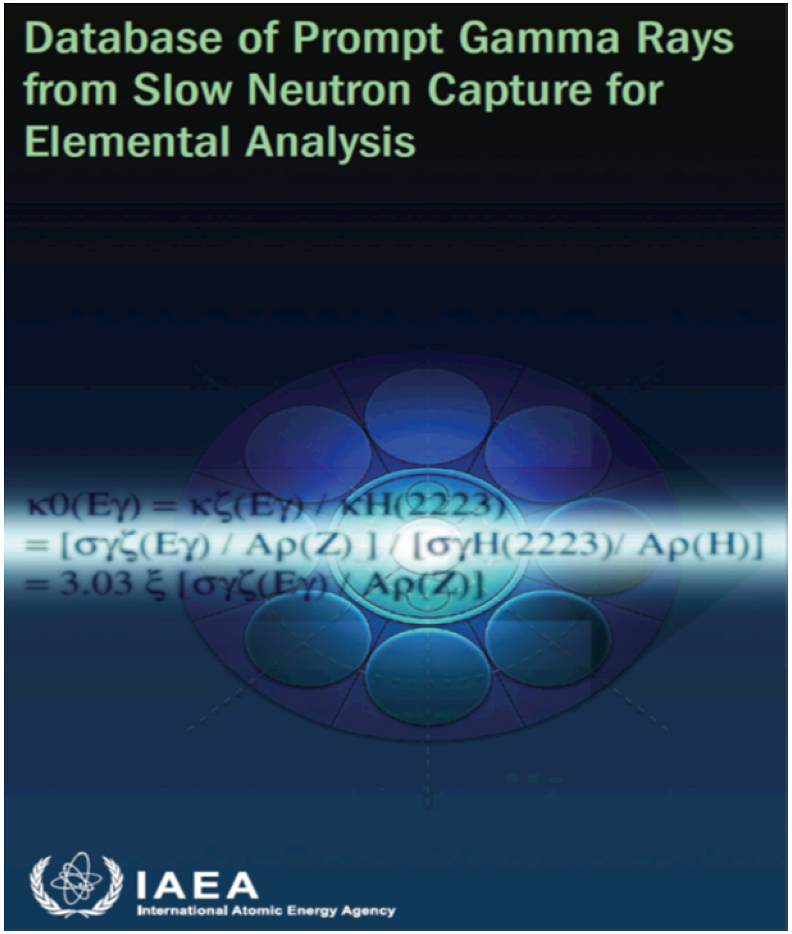


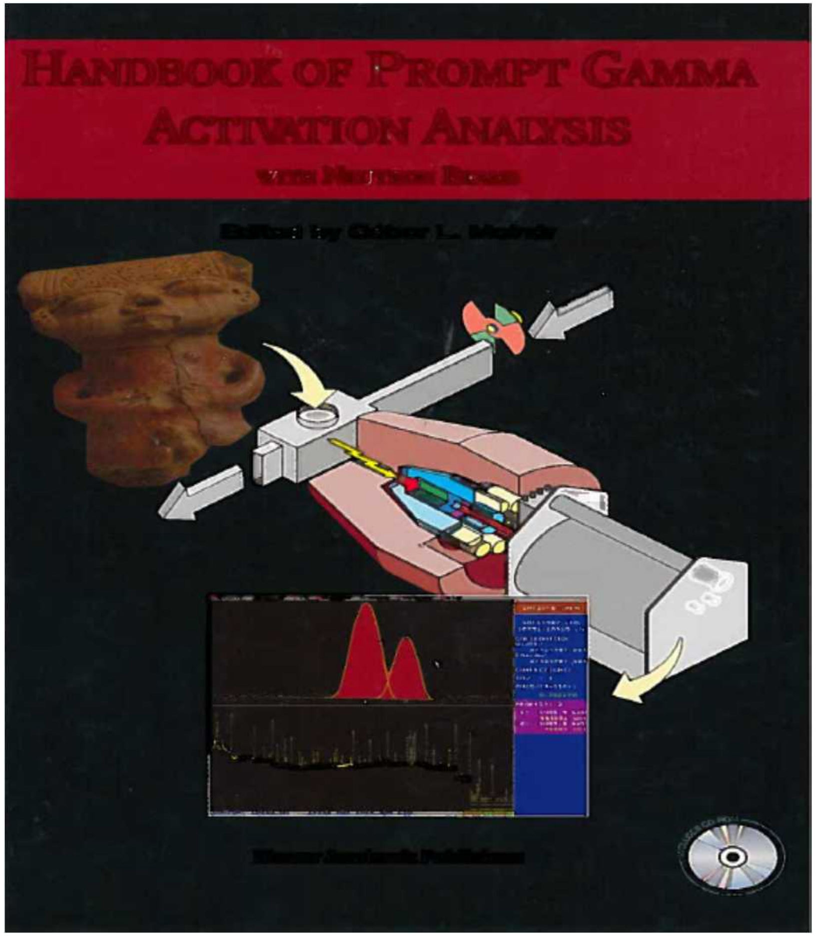


Some libraries have no spectra P, (Actinides)

Others have poor resolution, missing lines, etc.

IAEA CRP Capture Gamma Spectra for ~260 Nuclei 36K lines ~ Budapest Reactor Measurements + FRMII





Rick Firestone, Tamas Belgya, Zsolt Revay, et. al.

Evaluated Gamma-Ray Activation File (EGAF)

-Cross correlated with ENSDF decay schemes
-Put into ENDF libraries for transport modeling to be in next ENDF release and 1st libraries available through BNL now

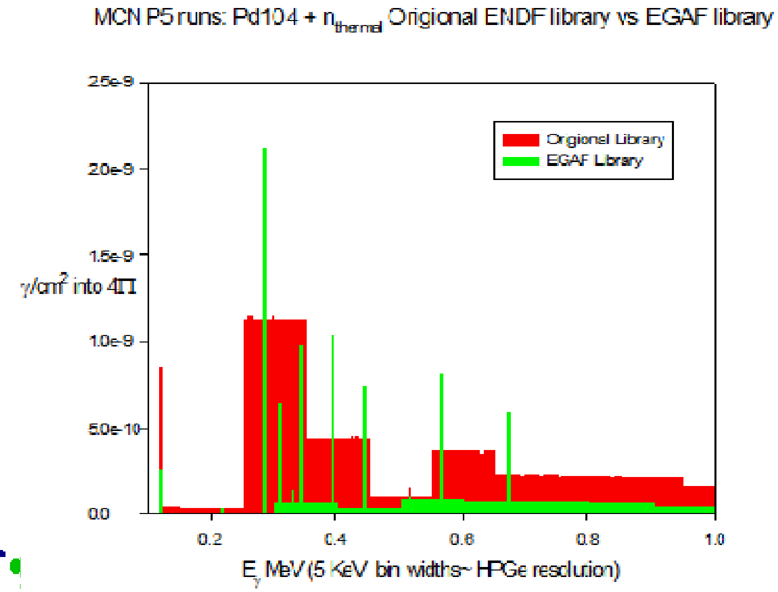
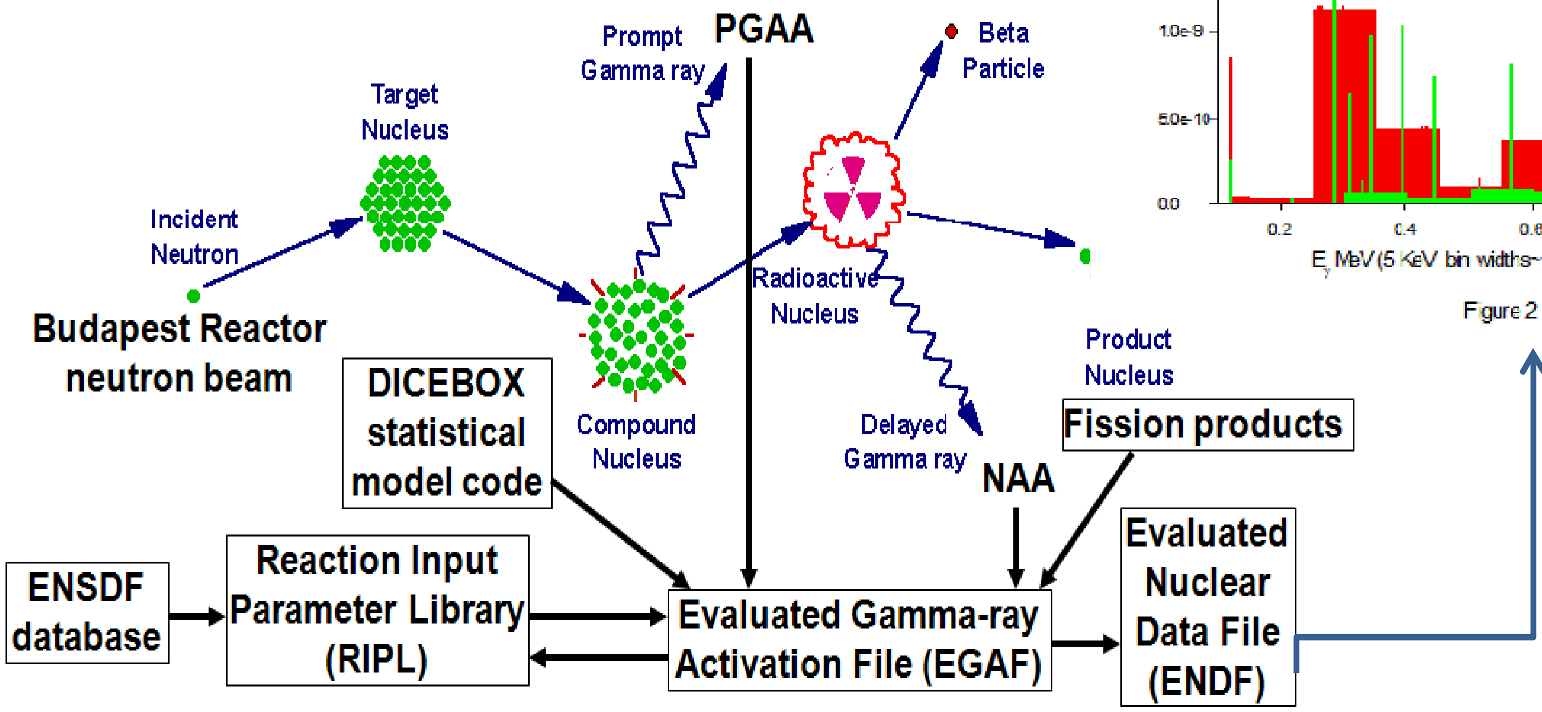
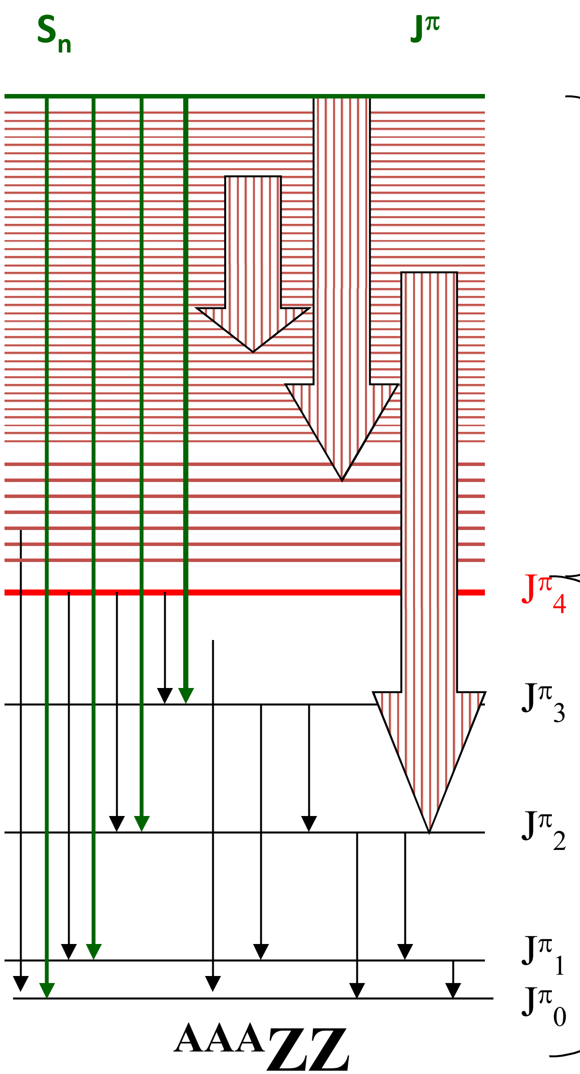


Figure 2



Gamma Cascade Quasi-Continuum in Medium-Heavy Nuclei modeled with Extreme Statistical model Dicebox (F. Becvar, M. Krticka)



Thermal neutron capture state energy and J^π value(s) are taken from experiment if known.

Monte-Carlo cascade: Capture->Ground State

Continuum=Energy bins above critical energy

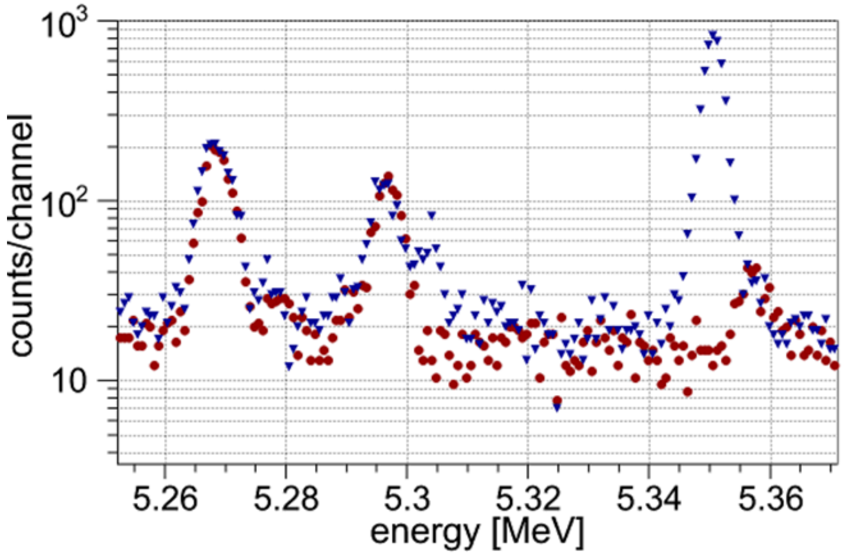
Partial widths calculated from presumed known level density and Strength function models

EGAF Data experimentally measured below critical energy

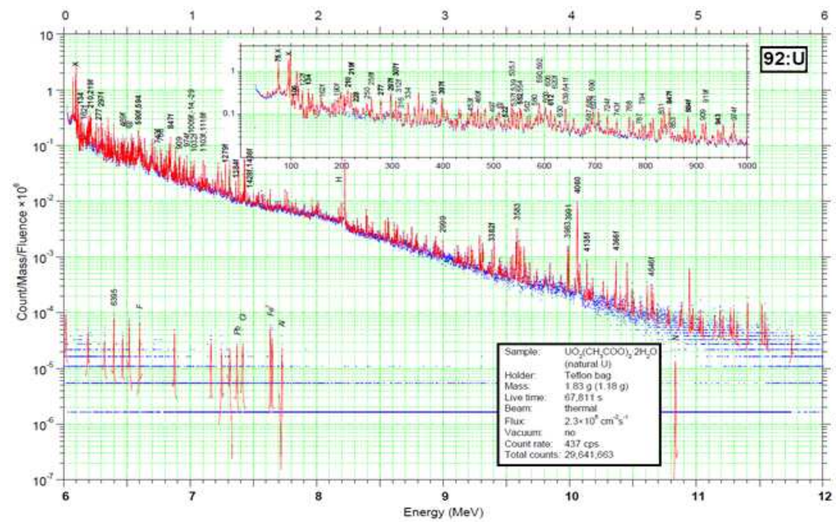
Total feeding to ground state now available=σ_{total}

Thermal Capture Gammas from Actinides New experimental Data being evaluated

Probable Primary Np237 line at 5.35 MeV

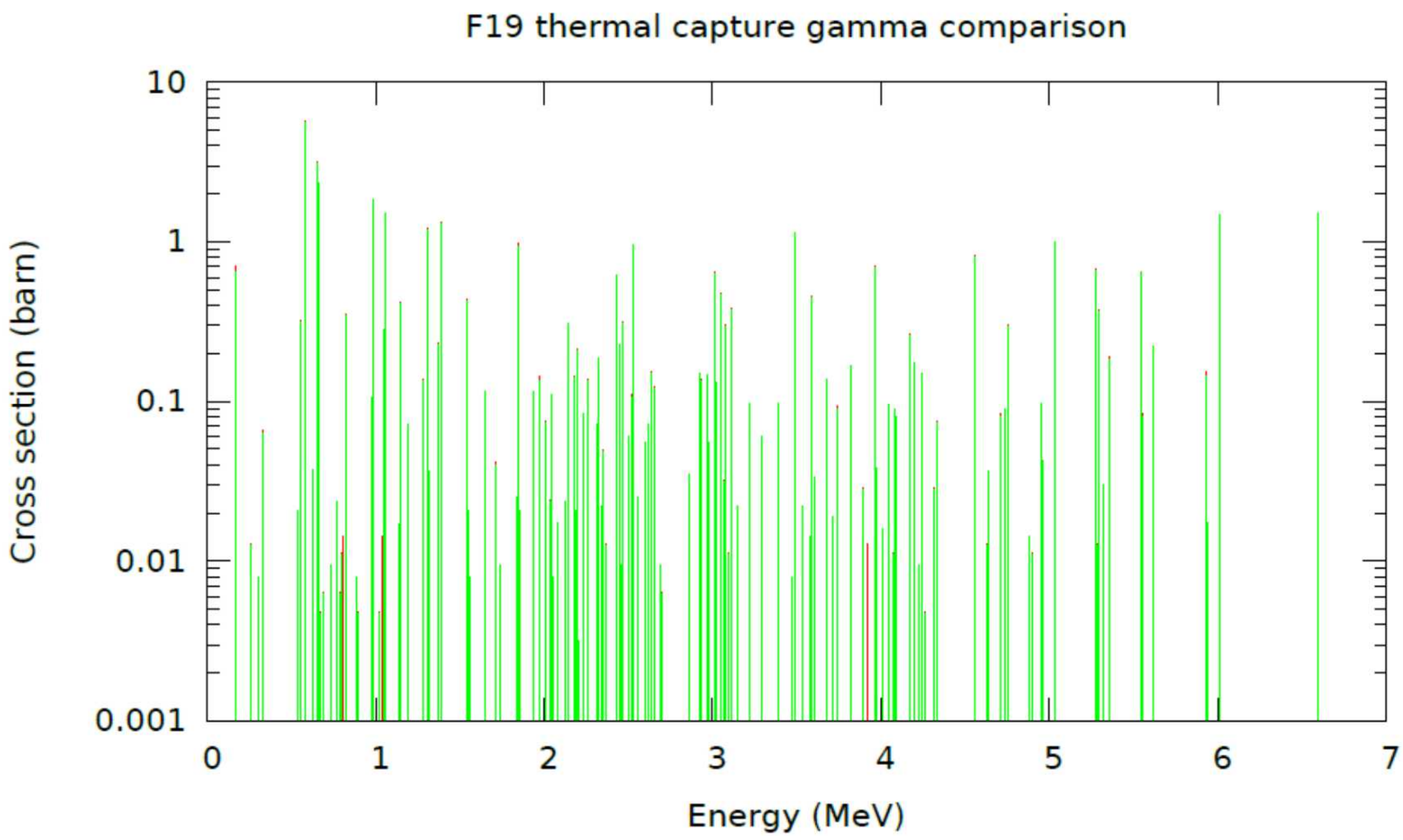


U235 Capture line @ 6.395 MeV is 4 mb



There are no high resolution capture gamma lines in the major actinides in ENDF

F had few changes



26 beta Libraries in testing->2 to BNL (Feb 2015)

Z		A	%NA	barns	number of Gammas
1	H	1	99.9844	0.33260	1
1	D	2	0.01557	0.00052	1
3	Li	6	7.589	0.04000	3
3	Li	7	92.411	0.05000	3
4	Be	9	100	0.01000	12
5	B	10	19.82	0.50000	9
5	B	11	80.18	0.01000	9
6	C	12	98.892	0.00353	6
7	N	14	99.6337	0.08000	60
8	O	16	99.7628	0.00019	4
9	F	19	100	0.00960	165
11	Na	23	100	0.53000	233
12	Mg	24		0.06000	283
13	Al	27	100	0.23000	291
14	Si	28	92.2297	0.18000	54
15	P	31	100	0.17000	202
16	S	32		0.53000	470
17	Cl	35	75.771	45.55000	383
17	Cl	37	24.229	0.43000	77
26	Fe	56	91.75	2.59000	193
46	Pd	104	11.14	0.60000	13
74	W	182	26.4985	19.90000	126
74	W	183	14.3136	10.30000	212
74	W	184	30.6422	1.70000	64
74	W	186	28.4259	38.50000	152
82	Pb	207	22.0827	0.62500	25

Capture Gamma Applications-Active Interrogation

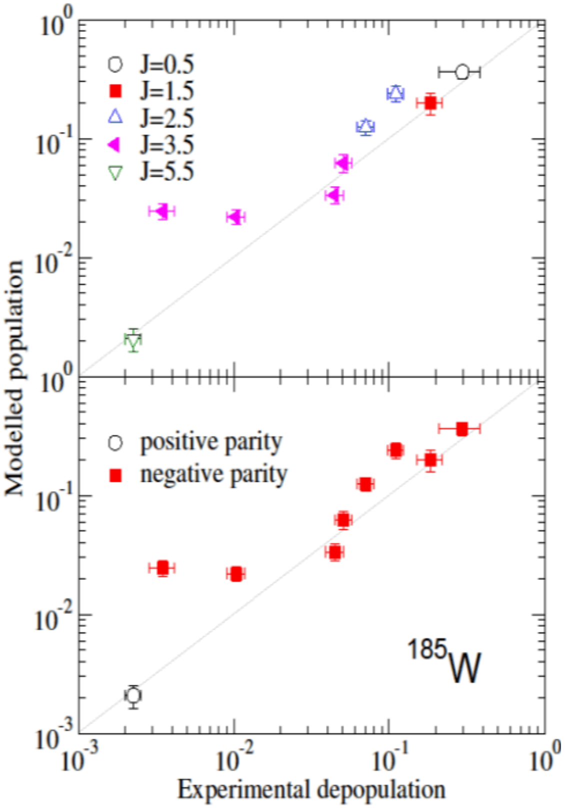
Evaluating munitions for presence of explosives, chemical or nerve agents

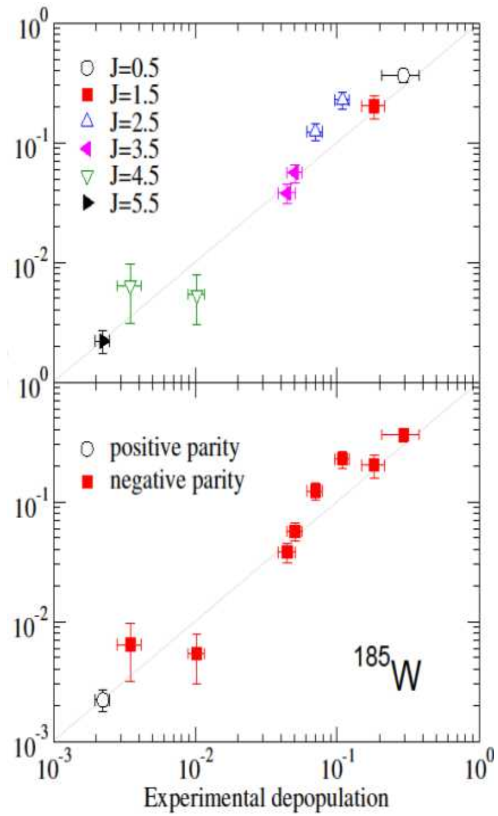
Idaho National Lab-
80 units in use worldwide

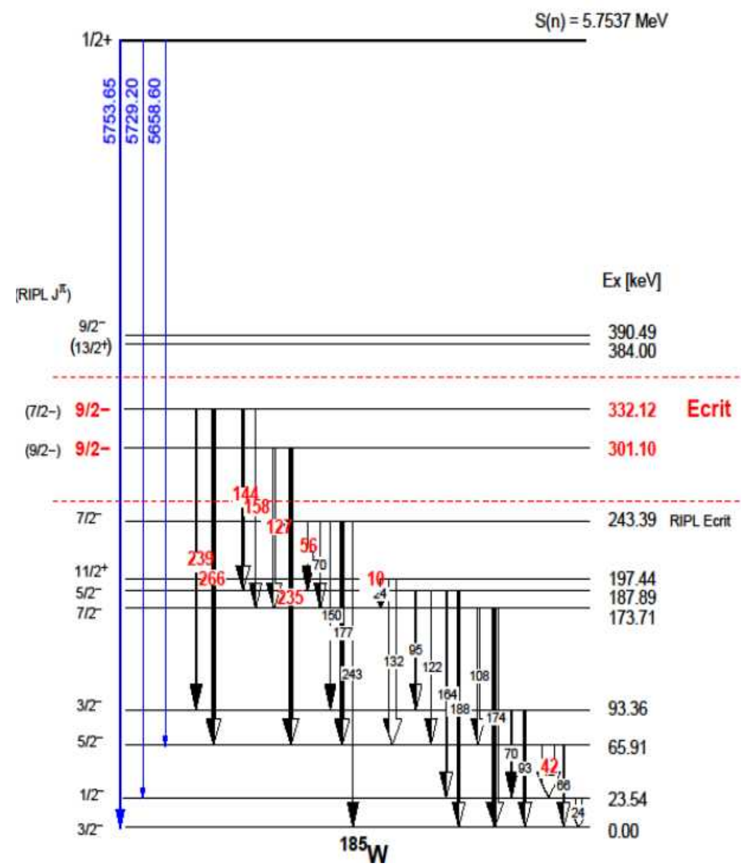
Spontaneous Fission, DD and DT neutron sources used

Gus Caffrey, Ed Seabury, INL

IAEA/EGAF targets are Elemental-ENDF libraries are Isotopic: Tungsten ENSDF Data had inaccuracies, ^{185}W, 9 levels below Ecrit– Dicebox population feeding vs Experimental depopulation





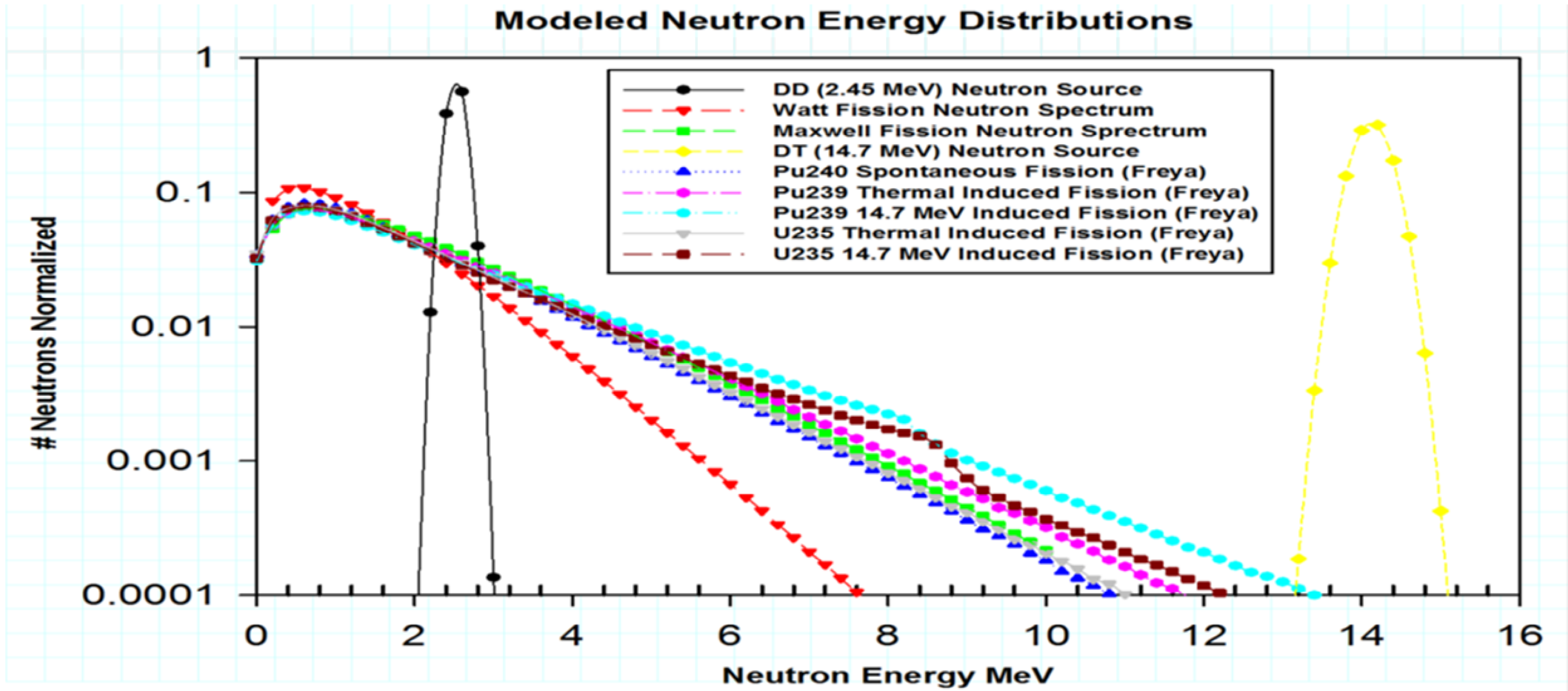


Aaron Hurst, et. al.

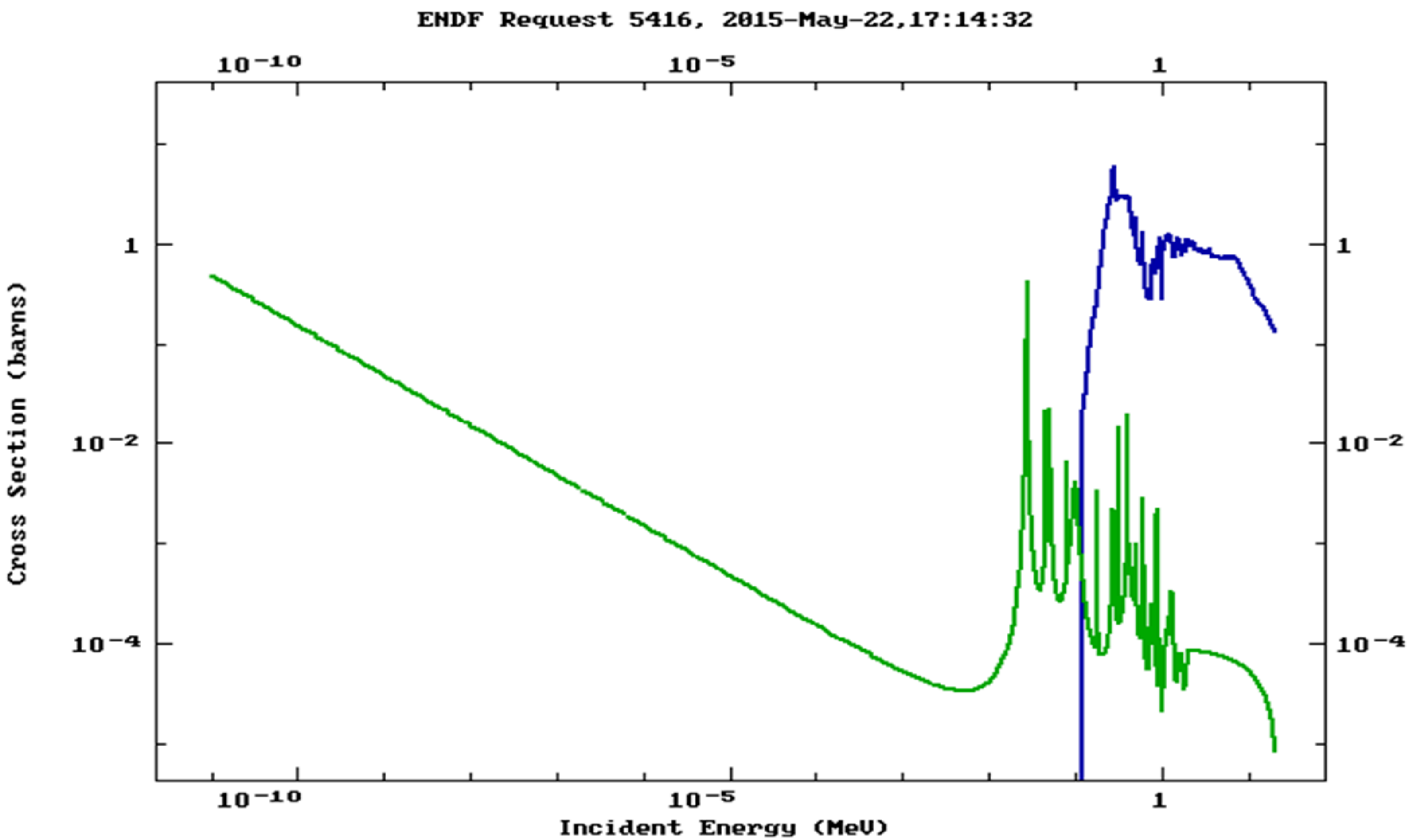
Neutron Spectra from Passive and Active Sources:

IAEA data is thermal reactor neutrons-Capture Dominates
Passive counting is mostly Spontaneous Fission neutrons
Active interrogation:
- DD spectra 2.45 MeV
- DT spectra 14 MeV
- National Ignition Facility is special case

Neutrons thermalize on ~μs time scale



At Higher Neutron Energies Inelastic lines dominate



A Carefully Done 1978 Atlas of HPGe Spectra from ~ 700 keV Neutrons: another Useful Database?

ATLAS

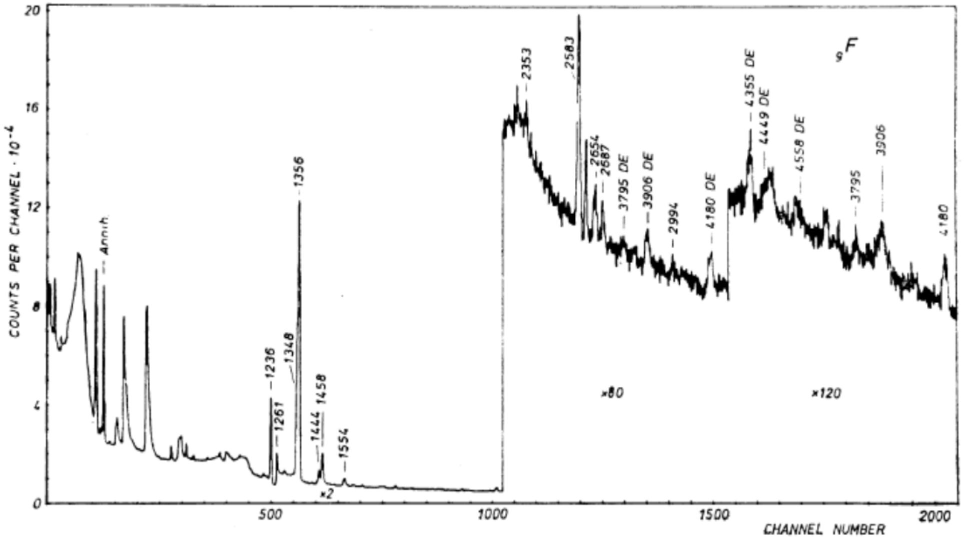
OF GAMMA-RAY SPECTRA FROM THE INELASTIC SCATTERING OF REACTOR FAST NEUTRONS

Level scheme of ^{19}F [72Aj]

E_i	E_i^a	J_i^π	E_γ	I_γ	E_f	J_f^π	P_s
109.9	109.893	1/2−	—	—	—	—	—
197.1 (2)	197.147	5/2+	197.1	2700	0	1/2+	2390
1345.74 (10)	1345.72	5/2−	1235.80	100	109.9	1/2−	91
1458.4 (4)	1458.5	3/2−	1458.0	33	0	1/2+	173
			1348.0	120	109.9	1/2−	
			1261.1	20	197.1	5/2+	
1553.9 (5)	1554.1	3/2+	1554.0	8.0	0	1/2+	286
			1444.0	15	109.9	1/2−	
			1356.5	265	197.1	5/2+	
2779.9 (3)	1779.80	9/2+	2582.6	20	197.1	5/2+	20
3906.2 (15)	3907.1	3/2(+)	3905.9	3.5	0	1/2+	6.5*
			3794.9	1.0	109.9	1/2−	
			2352.6	1.0	1553.9	3/2+	
3999.6 (6)	3998.5	7/2−	2653.8	5.4	1345.7	5/2−	6.8*
4032.5 (6)	4032.5	9/2−	2686.6	3.7	1345.7	5/2−	3.7
4377.9 (16)	4377.7	7/2+	4180.2	3.0	197.1	5/2+	4.0*
4552.4 (225	4555	5/2+	4354.8	2.0	197.1	5/2+	3.0*
4558.9 (5))	4557.5	3/2−	4558.3	2.0	0	1/2+	4.9*
			4449.3	2.0	109.9	1/2−	

A. Demidov, et. al. Kurchatov Institute, Moscow

^{19}F Spectra Atlas 2 ENDF?



Atlas (n,n')			ENDF (n,n')	
Fluorine			MF3 MT51	1.099000+5
197.1	8.17E-01		52	1.970000+5
1235.8	3.03E-02			
1261.1	6.05E-03			
1348	3.63E-02		53	-1.346000+6
1356.5	8.02E-02			
1444	4.54E-03			
1458.4	9.98E-03		54	-1.459000+6
1554	2.42E-03		55	-1.554000+6
2352.6	3.03E-04		56	-2.780000+6
2582.6	6.05E-03			
2653.8	1.63E-03			
2686.6	1.12E-03			
2993.6	3.33E-04			
3794.9	3.03E-04			
3905.9	1.06E-03		57	-3.907000+6
			58	-3.999000+6
4180.2	9.08E-04		59	-4.032000+6
4354.8	6.05E-04		60	-4.378000+6
4449.3	6.05E-04		61	-4.549000+6
4558.3	6.05E-04		62	-4.558000+6
			63	-4.648000+6
			64	-4.683000+6
			65	-5.106000+6
			66	-5.366000+6

Fluorine $_9$F

E_γ	I_γ	E_i	E_γ	I_γ	E_i
197.1 (2)	2700 (200)	197.1	2653.8 (5)	5.4 (13)	3999.6
1235.80 (10)	100	1345.7	2686.6 (5)	3.7 (13)	4032.5
1261.1 (3)	20 (4)	1458.4	2993.6 (20)	1.1 (3)	
1348.0 (5)	120 (30)	1458.4	3794.9 (15)	1.0 (2)	3906.2
1356.5 (5)	265 (60)	1553.9	3905.9 (15)	3.5 (18)	3906.2
1444.0 (4)	15 (5)	1553.9	4180.2 (15)	3.0 (8)	4377.9
1458.4 (4)	33 (6)	1458.4	4354.8 (25)	2.0 (10)	4552.4
1554.0 (6)	8.0 (22)	1553.9	4449.3 (25)	2.0 (10)	4558.9
2352.6 (12)	1.0 (3)	3906.2	4558.3 (25)	2.0 (10)	4558.9
2582.6 (2)	20 (3)	2779.9			

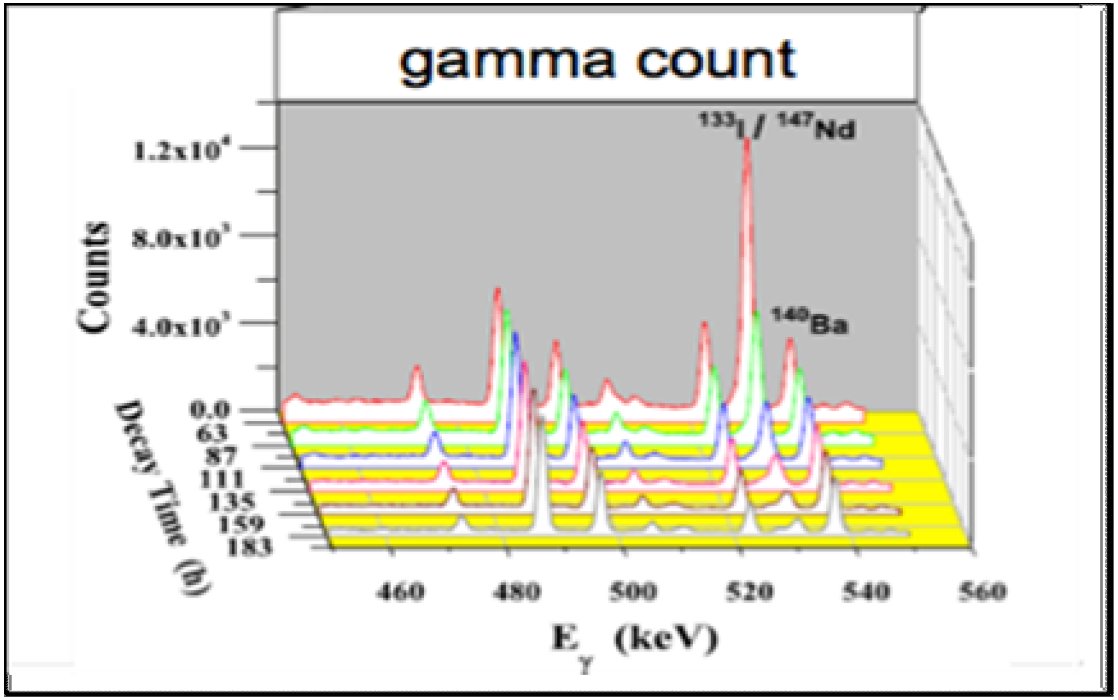
Attempts at modeling spectra not convincing
Cascades/cross sections not matching up?

ENDF references ORNL measurements using NaI gamma spectrometers?

Definitely Worth Further Evaluation

Improved High Resolution Gamma Spectra of Fission Products-What Actinide?

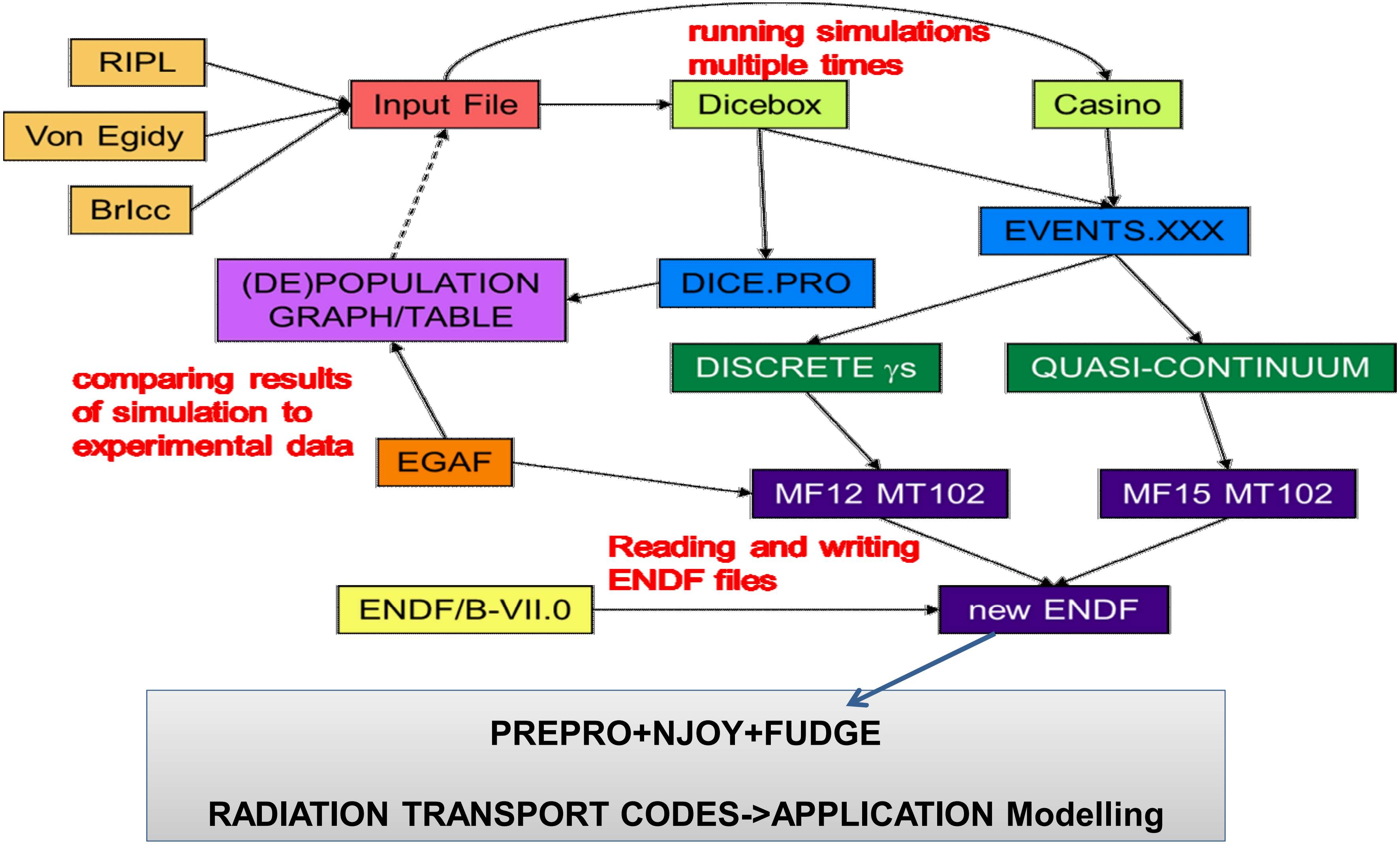
State of the Art New Spectroscopy data: Time Dependent HPGe spectra from 15 High Yield Fission Products from
235U, 238U, 239Pu Fissioned by 5 narrow Neutron Energy Distributions



This New data should be in ENDF+233U, other Pu, 237Np

A. Tonchev, et. al.

Evaluation Automation



Neil Summers, Brad Sleaford, LLNL